Wind Turbines and the Future of Clean Energy

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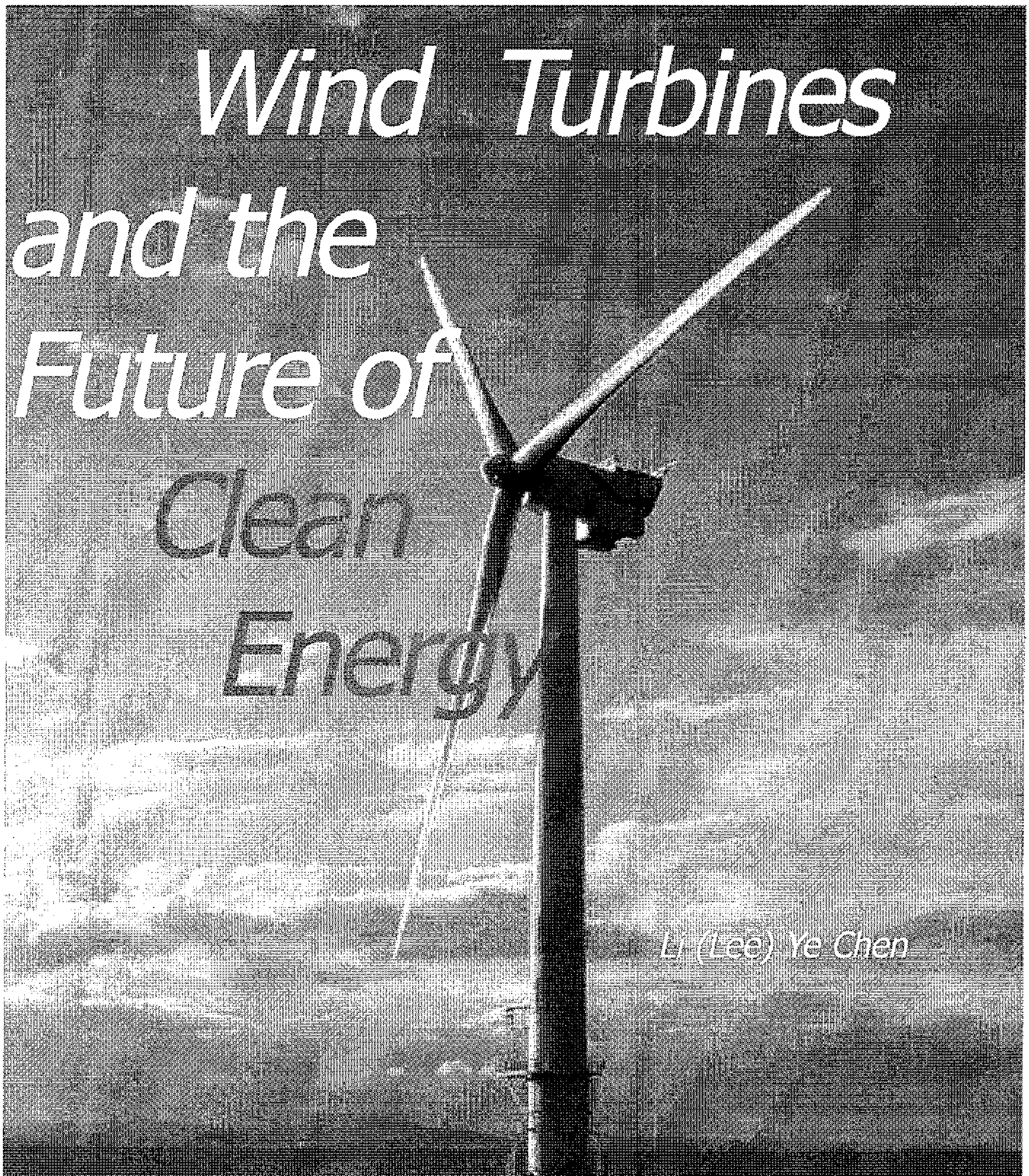


Imagine standing on a flat stretch of farmland on a sunny day, and hearing the gentle "*swish, swish, swish...*" sounds in the air. What might surprise you is that the sounds do not come from the wind, but rather, the majestic white wind turbines stretching high into the sky. SciTech has conducted an interview with Jim Lyons (1984 Cornell Ph.D.), Chief Engineer at GE Global Research and Advanced Technology Leader for General Electric's wind energy business. Mr. Lyons gives us more details about the successes-to-date and the future prospects of this technology.

Image Source: General Electric Company

Wind turbines are typically giant propellers mounted on a high-rising tower, and are among the most promising sources of renewable energy. They convert pervasive wind into electric energy that can power residential and commercial buildings without incurring any air or water pollution as unwanted side effects. Some wind turbines can provide 3,600 kilowatts of electric capacity, which is more than enough to provide energy for 1200 average American homes (using AWEA's calculation model).[1] Essentially, wind turbines convert the kinetic energy from the wind (created when wind hits the propellers) into electrical energy via a rotating "drive train" mounted behind the propellers. Of course, how well a wind turbine exploits the power of the wind depends on a few crucial factors: the design of the propellers, drive train, and the power electronic converter (which couples the turbine generator to the grid), the location of the wind turbine, the machine's ability to adapt to changing wind conditions (i.e., facing the direction of maximum wind flow), etc. Wind turbines are typically built in clusters, so that they form a "wind farm" with anywhere from a few to over a hundred wind turbines, with the ability to be "scaled" up or down to meet energy demands. While turbines may be more expensive than conventional generation to install in the short run, with zero fuel expense the cost amortizes itself in the long run, bringing additional benefits of an unpolluted environment.

The size of the biggest wind turbines is about 3.6MW, but it's difficult for readers to imagine just how big this really is. I once saw a model of a GE turbine next to a cow – the cow was incredibly tiny in comparison. Can you give us a better idea of the size of these devices?

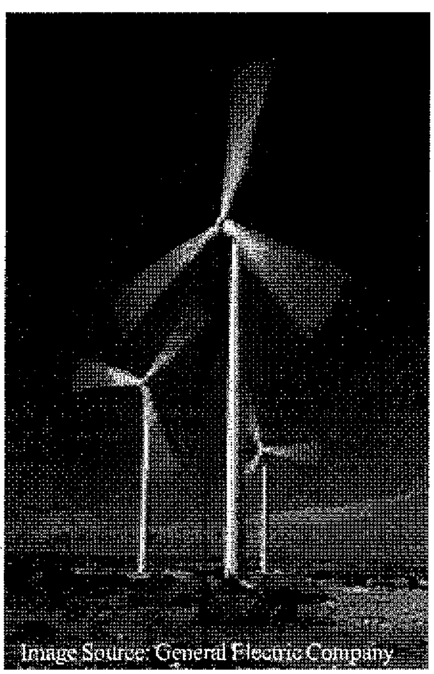
In Fenner, NY, the 1.5MW wind turbines have 70-meter rotors [wider than the wingspan of a jumbo jet], and the blades are 34 meters long and weigh 5 tons each. Our biggest machine is a 3.6MW offshore wind turbine, and our offshore pilot project in the Arklow Banks of the Irish Sea has wind turbines with 104-meter rotors [which can sweep the size of a football field] and 50.5 meter blades (weighing 14 tons). They rise about 70 meters above the water line [about as tall as a 30-story building].

With winds being stronger at sea, does it follow that wind turbines in the sea are larger than those on land?

Yes, that is correct. The first generation of sea-based wind turbines is in the 3MW class, and the next round of machines will be between 5-7MW. According to the industry consensus, to make the offshore [sea-based wind turbines] economic, we will need more power per foundation. However, the economics for land-based wind turbines are currently satisfactory at good US wind sites.

Why did GE choose to produce wind turbines for the commercial market? Given that a typical wind turbine extracts only 10% to 20% of the energy from the wind, it seems to be a very challenging market to penetrate successfully. Does GE predict worldwide growth of the product, and if so, how?

I am somewhat responsible for this decision since I lead the technology team that brought us into the wind business. A typical U.S. wind turbine site—i.e., a Great Plains site—from West Texas up through Minnesota will have a capacity factor in the 33%+ range, *not* 10 to 20%. Offshore, capacity factors are even higher, averaging 45% and higher. Our state-of-the-art product in West Texas will produce energy at about 4.5 cents/kWh *without* subsidies. But the U.S. has a so-called production tax credit system, which provides a 1.8 cents/kWh tax incentive, and is designed to level the playing field with fossil fuels (which receive a depletion credit). So taking 1.8 cents/kWh off the existing cost of 4.5 cents/kWh brings us to the low 3 cents/kWh range, which is the *cheapest* way to generate new electricity. Even better, our new generation of products will take another 1 cent/kWh off the cost. Wind energy has a cubic relationship with wind velocity, so the wind velocity is really what matters. The typical U.S. site that we build today has an average annual wind speed of 8 to 8.5 m/s

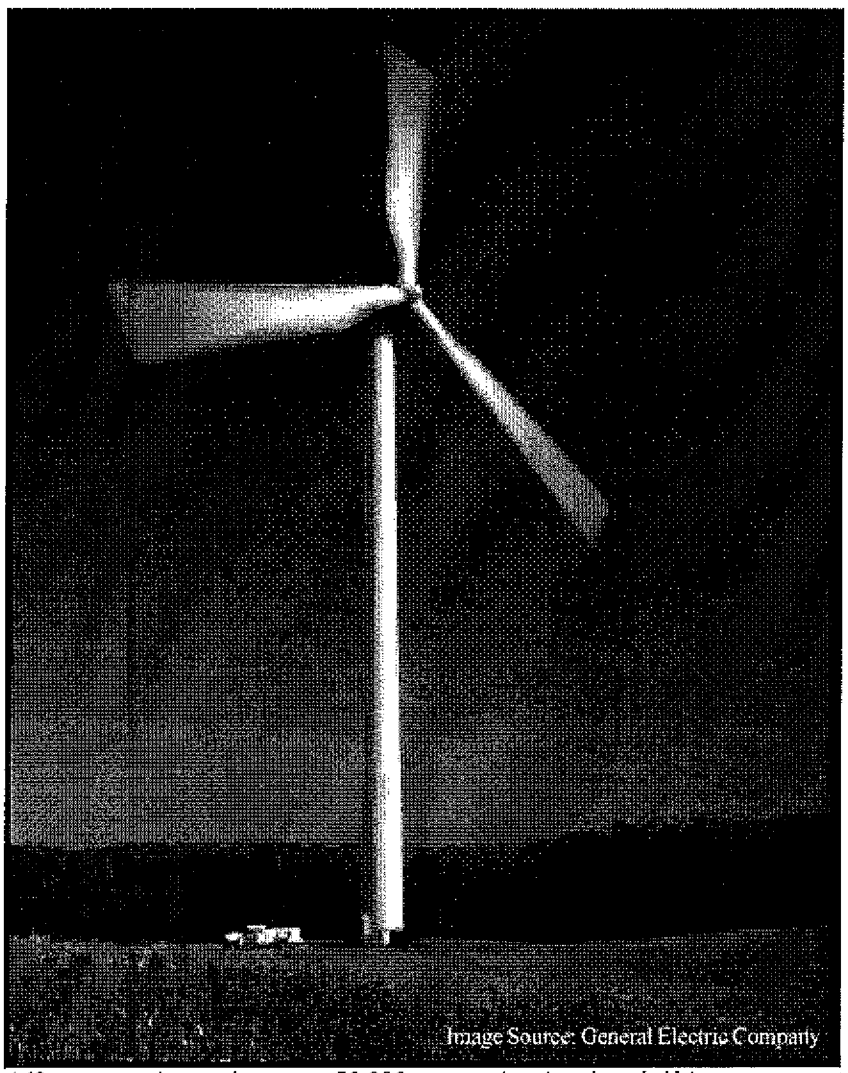


Capacity factor = *(Actual amount of power produced over time) / (Power that would have been produced if turbine operated at maximum output 100% of the time)*[1]

kWh = *kilowatt-hour* **m/s** = *meters per second*

Hub height = *roughly the height of the nacelle at the top of the wind turbine*

wind-velocity at hub height. Even in less-windy sites found in upstate NY (7 to 7.5 m/s wind speed), we will still be able to generate electricity competitively compared to any other fuel source (about 6 cents/kWh). To summarize the economics, wind is rapidly becoming the most inexpensive way to generate energy. However, because it is intermittent, it can be a complicated source, but as far as an energy supply, it is very cost effective and it's becoming more effective over time. We are starting to see customers buy wind turbines as a hedge against volatility in natural gas prices.



162 megawatts is enough to power 52,000 average American households!

In short, we have two reasons: first, we see the market booming world wide and, second, we thought that it was a technology that GE could excel in – it is quite synergistic with the other equipment that we make.

*"**Size perspective:** if the rotor of an offshore wind turbine is shrunk to 1 ft. long, a cow of comparable size would be only 0.14 inches high!"*

What is the biggest or most successful wind farm that GE has built? How has this wind farm helped the local community or region?

I'll describe a couple of the modern farms where we have supplied wind turbines. One is in Lamar, Colorado; it's called Colorado Green Project (CGP). Owned by PPM Energy and Shell Wind Energy, it is a 162MW site, located in eastern Colorado on the Great Plains. Just south of that is the New Mexico Wind Energy Center – a 204MW site owned by FPL Energy – in the Taiban Plateau of New Mexico. The CGP site is extremely successful *economically*; it is a very rural area and the project increased the tax base [the county's income, assets, etc] of the county by 40 percent. The local ranchers and farmers love them because they bring a steady source of high income to the area.

I think the CGP site was also a *technologically* successful implementation, because to put such a large farm with an intermittent power onto the grid, stability is a challenge to the electrical controls of the wind farm. Much of the older technology lacks sufficient power electronic interfaces, and would not be able to operate stably without frequent voltage fluctuations due to the intermittence of the wind flow. Our modern variable-speed wind turbines use power electronic converters for "variable frequency" to "constant (grid) frequency" conversion. These responsive converters enable quick control of both real and reactive power. Reactive power is needed to compensate for inductive line drops in transmission lines and transformers, and the net result is to smooth voltage fluctuations and eliminate flickering even in the face of varying winds.

The other technical success was the development in New Mexico of what we call "low voltage ride through,"[2] for the Public Service Company of New Mexico and Florida Power and Light Company. Early wind turbines were

designed to come offline during a grid disturbance. Traditionally, wind turbines wait for the grid to re-stabilize and then resynchronize with the grid. If 20 percent of the energy is being supplied by wind power, and if the grid wiggled in frequency and that 20 percent just dropped off-line, the grid would rapidly collapse. So at significant penetration levels, that strategy no longer works. With "low voltage ride through," we can stay synchronized to the grid (the "ride-through capability") down to 15% grid voltage for up to 500 milliseconds, and still feed real and reactive power into the grid while it is stabilizing. Even if lightning struck 50 miles down the transmission line, the wind farm will still stay synchronized like the rest of the conventional power generation equipment. This is very important for "grid friendliness."

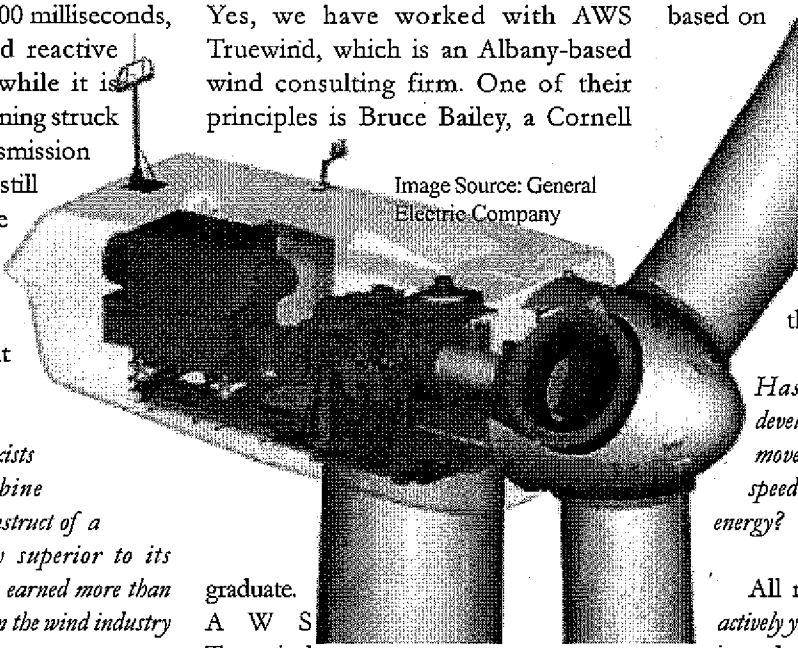


Image Source: General Electric Company

The same basic technology exists behind every wind turbine produced. How is GE's construct of a wind turbine technically superior to its competitors, given that GE earned more than $1.2 billion in revenues from the wind industry in 2003?

GE's product families were very comparable in energy performance during 2003 with our top competitors. What we're really focusing on is *reliability*: making our machines as bullet-proof as possible, and offering long-term service agreements to our customers. We feel that we understand that kind of electrical grid performance better than anyone else in the industry, and have implemented grid-friendly control features into our turbines and wind farms -- that's what the utility companies worry about. And, we did start a full-fledged research and development project when we entered the wind business; it was integrally part of our plan. So in the next generation of technology we expect to see significant differentiators for *reliability*, *performance*, and *simplicity*.

The infrastructure costs of wind turbines are higher than those of conventional power plants due to the higher "idle time" of wind turbines, so any engineer will appreciate the challenge of selecting the best location for a wind farm. Has GE developed any high-tech means to select a location that maximizes the energy extracted from the wind?

Yes, we have worked with AWS Truewind, which is an Albany-based wind consulting firm. One of their principles is Bruce Bailey, a Cornell graduate. AWS Truewind produces "meso-scale" maps that combine wind measurements and physics based models to predict annual average wind velocities. Based on those maps, we look at the confluence of roads, transmission lines, and windy sites predicted by these physical models, and locate the best sites for wind turbines. To finance a wind farm, you need to have about a years' worth of measured data at minimum. The capital cost for a state-of-the-art gas turbine (a conventional energy source) would be approximately $350/kW while a comparable wind turbine would cost $900/kW. However, the difference is made up in *fuel* costs. The wind turbine's are a high up-front capital investment, but with no "fuel" costs: operation and maintenance costs are low compared to (say) coal plants or gas turbines, and so the total energy cost is very competitive compared to conventional energy sources.

So the costs are amortized over time?

Exactly. Most financing is done for 13 years. You need to look at the developers' return on investment, which varies significantly around the world based on regulatory policy and power purchase rates. This is quite dependent on natural gas prices. I previously talked about hedging: since natural gas prices are being forced up, people are looking at wind turbines as a hedge against the raising cost.

Has GE developed, or is GE developing, wind turbines that can move to face the maximum wind flow speed in order to extract the most energy?

All modern wind turbines are *actively yawed*: that means they rotate into the wind, normal [in angle] to the wind flow, by motor operation. They are constantly adjusting themselves to the maximal wind flow. There is a cable loop inside the tower and typically it can twist around up to 3 times before it needs to untwist. This allows the yaw deck and bearing on the top of the tower to rotate the nacelle (a structure that sits on top of the tower and is connected to the rotors). Usually, it takes 4 motors to rotate the nacelle.

Some environmental groups contend that wind farms may have negative effects on animals (like birds and bats). How has GE worked to optimize the wind turbine technology to be compatible and safe for its environment?

That issue comes up frequently. One of the first farms in the U.S. is the Altamont Pass near San Francisco, which is most likely the worst place in the world for avian mortality. It was built in the early 80's before a lot was known about siting issues. The Altamont Pass is a natural fly-away for some bird species. In addition, there is a large concentration of raptors in the area. Wind turbines were smaller in the 80's, so they tend to spin very fast in terms of rpm's (rotations per minute). However, as turbines increase in power (in more modern models), the rotor diameter increases, and to keep the tip velocity constant, the rpm decreases. The modern turbines only rotate 15-18 rpm versus rotating at 100 rpm in the past, which is too fast. Also, in the past, they were built as "down-wind" machines with lattice towers, which provided convenient places for the birds to land and build nests. The modern turbines are all "up-wind"; in other words, the rotor is on the upwind side and has tubular towers with no places for the birds to land on. So the avian mortality on modern wind farms has been dramatically reduced compared to the Altamont site.

Today, environmental impact studies are done to avoid "siting" mistakes. If we look at the avian mortality on wind turbines compared to plate glass windows, there are tens of thousands more birds killed flying into plate glass windows. In comparison, the relative fatalities are small when it comes to wind energy, with a couple of exceptional sites world-wide. UK offshore, for example, has permitted many zones for the proposed offshore farms. But before doing that, they studied the bird migratory patterns, so they would be able to strategically locate wind farms to minimize the harm to birds. Bats are a new issue that has been discovered in West Virginia in the last year, and that is not well understood. There is some discussion that the small bats are not hitting the wind turbines, but rather, they are getting confused in the wake of the turbines [a wake is "the region of turbulence immediately to the rear of a solid body caused by the flow of air or water around the body."[11]]. There are currently research teams trying to find the reason behind the bat issue.

*Annual avian mortality[10] from collision with windows: **98 million.***
*Annual avian mortality[9] at the Altamont wind site: **92.***

What is the projected lifetime of a particular GE wind farm? Environmentally-conscious people may be interested in this question when accessing the environmental-impacts of wind farms.

We design our turbines for a 20-year life. Currently, some of our components get rebuilt before then, like gearboxes and bearings – typically in the 10 to 12-year range – but we're pushing towards keeping the full 20-year life. The interesting part is that the turbine rotors have some of the highest fatigue life needs of any products that are built – it is on the order of 3×10^8 fatigue cycles in the 20-year period, and this really pushes the limit of the composite material.

Does GE Energy have any partnerships with universities for the wind energy initiative? Where can Cornell students find information about opportunities to get involved with GE Energy in this type of technology?

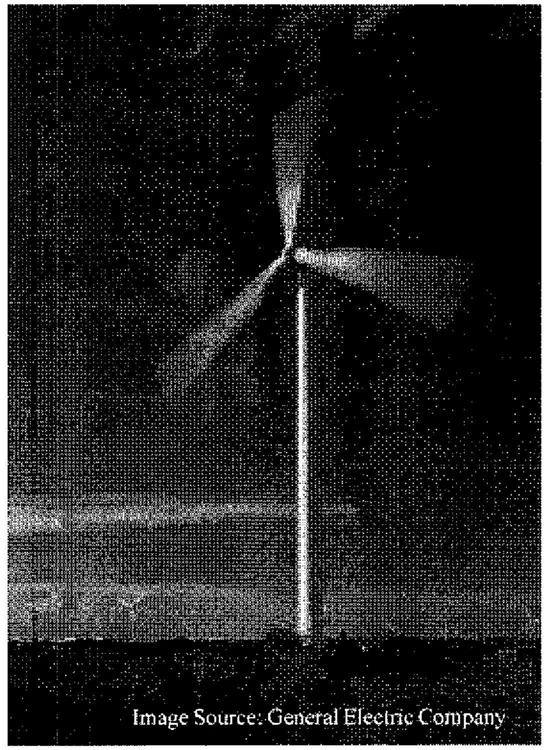
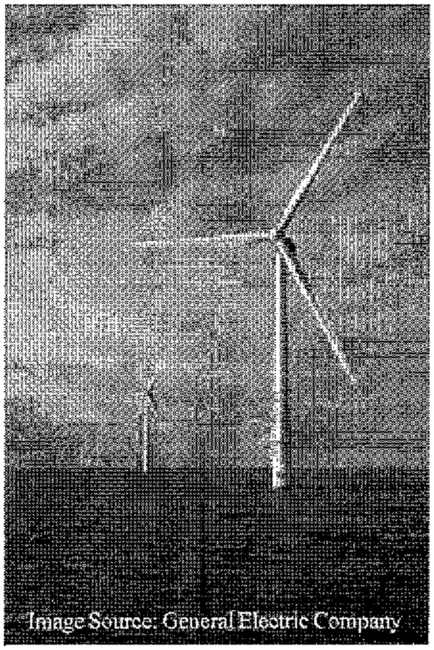


Image Source: General Electric Company

We have a full team working at GE Global Research Center[4], so graduate students can intern here if they are interested in wind turbines. I gave a talk on wind technology last year to the Mechanical Engineering Department at Cornell. We have engineering teams here in the U.S. in California, South Carolina, and Schenectady, NY working on wind turbines within the GE Energy business, so there are engineering opportunities. We are currently forming an off-shore wind energy consortium with the Department of Energy and the state of Massachusetts, so there are possibilities of working on joint projects with NYSERDA, Cornell, and GE. We just finished a study with NYSERDA[7] and NYISO[8] putting 3.3 gigawatts of wind power in Upstate NY. The ECE Department at Cornell would be very well suited to assist in such a study.

Can you supply some comments from the people who have worked on the GE wind turbines on how they feel about this technology?

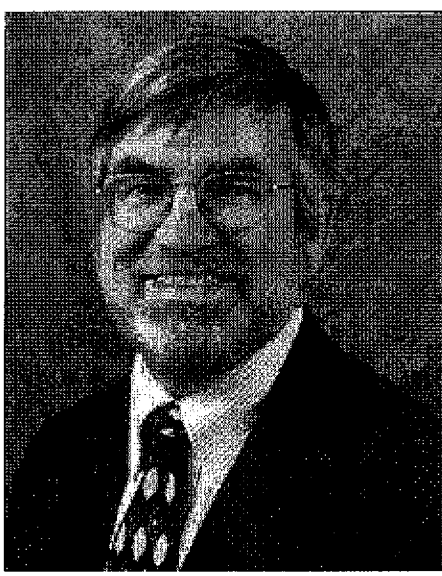


The public acceptance about GE getting into the wind business has been pretty outstanding. We entered it because we thought it was a very good business. I gave many public talks last year on wind technology and many interviews (*New York Times*, *IEEE Spectrum*), so there is a huge amount of public interest. Wind is the first truly viable renewable energy in which the cost is sustainable. Once the utility companies understand how to use it, integrate it with their system, and get to like it, it will be a highly viable alternative to fossil-based fuels.

Almost every researcher that is working on wind turbines *approached me*. I didn't have to recruit anyone, since they came to me and said "I want to work on wind turbines." There is a lot of excitement, and people like working on this technology – it makes you feel good when you are working to make the world a better place! We have a whole team in Germany that is very "green conscious". Germany has 15 gigawatts of installed wind power, and to put that into perspective, Northern Germany is about the size of New York State (NYS). The demand in NYS is about 33 gigawatts on a daily basis, so this means Germany derives about half the power of NYS from wind.

I find wind a very exciting business to be in. It is booming world-wide. When we started the business 2½ years ago it was essentially four countries: Germany, Denmark, Spain and the U.S. Now we are active in 30 countries; Australia, Spain, Japan, and China are growing rapidly. The Chinese government is discussing 26 gigawatts of potential projects. Canada is huge; there are potentially 10 gigawatts of projects in Canada. Norway, Portugal, and France are among the places that are very interested in this source of power. India has a very active program and Brazil is starting to talk about it. But I think it is in Canada and China that we will see an explosive growth in wind in the next 2 to 3 years. The offshore wind projects are very promising, too. UK will lead the way with 23 gigawatts of planned offshore projects. Germany is thinking about 20 to 60 gigawatts of offshore projects. So it's starting to spread world wide.

We also have a vision for the East Coast of the U.S.: Boston, Philadelphia, and NYC have some of the highest cost of electricity in the U.S., so the ability to put 5 gigawatts of power to, say, 5-8 miles offshore and feed renewable energy into NYC and to undercut at less energy costs than they are paying today, is pretty stunning and we think we can get there. The Department of Energy thinks we can get there. There is still a ways to go to make the offshore wind turbines as economic as we would like to see them, but it should come to fruition by the 2012 to 2014 time frame. I think that prospect is pretty unbounded and the amount of energy offshore is truly enormous.



James P. Lyons
Advanced Technology Leader, GE Wind Energy
Chief Engineer – Electronics & Energy Conversion, GE Global Research

Education

BSEE	Rensselaer Polytechnic Institute, 1970
MSEE	Virginia Polytechnic Institute, 1981
Ph.D.	Cornell University, 1984

Experience

Dr. Lyons joined GE in 1970 with field assignments in industrial control, automation, and power systems. Graduate academic studies concentrated in control systems and computer science with a PhD thesis on Variable Speed Wind Turbine Generators.
Dr. Lyons joined GE Research in 1989 and in 1999 was appointed Chief Engineer for electrical & electronic systems with responsibilities for product applications across all GE businesses. He has been the corporate champion for wind energy within GE.

Affiliations, Publications, and Patents

Dr. Lyons is a member of the IEEE Industry Application, Computer, Power Electronics, Power Engineering, and Automatic Control Societies. He has authored more than 25 technical papers and has been awarded 28 patents.